National Aeronautics and Space Administration

STS–107: Space Research and You

Using Microgravity to Understand Soil Behavior

Mechanics of Granular Materials–3 (MGM–3)

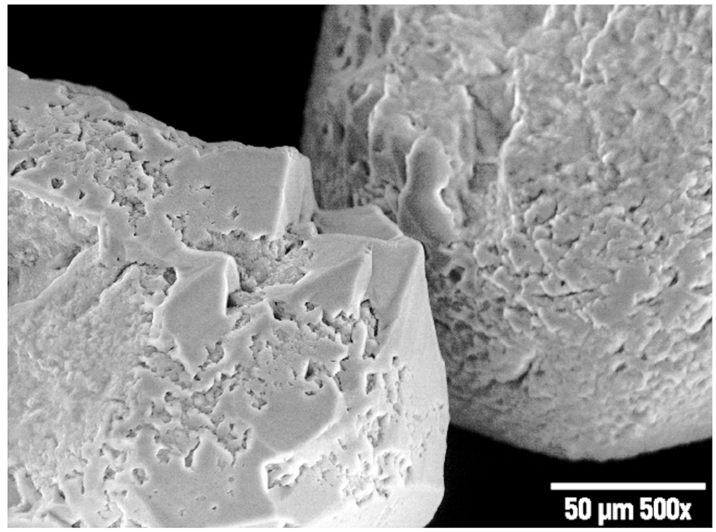
Rip open a vacuum packed pouch of coffee and you experience a fundamental aspect of granular mechanics: a simple shift in conditions drastically changes the properties of a bulk material. Once pressures are released, the grain assembly becomes weak and soft, and moves about freely, almost like a liquid.

This can happen to saturated, loose sand in an earthquake or to grain in a silo. During this critical, unstable state, gravity can collapse the grain assembly and destroy a building or a silo. Detailed understanding of this phenomenon is needed to improve techniques for evaluating building sites here on Earth and, eventually, on the Moon and Mars, and to improve industrial processes with powdered materials. Research can only go so far on Earth because gravity-induced stresses complicate the analysis and change loads too quickly for detailed study.

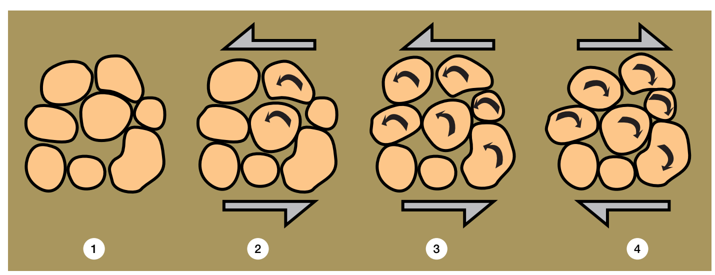
Soil liquefaction during the Oct. 17, 1989, Loma Prieta earthquake made this apartment building in San Francisco's Marina District sink, putting the third story at ground level.

The Mechanics of Granular Materials (MGM) experiment uses the microgravity of orbit to test sand columns under conditions that cannot be obtained in experiments on Earth. This new knowledge will be applied to improving foundations for buildings, managing undeveloped land, and handling powdered and granular materials in chemical, agricultural, and other industries.

Principal Investigator: Dr. Stein Sture, University of Colorado at Boulder
Co-Investigator: Dr. Nicholas Costes, University of Colorado at Boulder
Project Scientist: Dr. Khalid Alshibli, Louisiana State University-Southern University, Baton Rouge, LA
Project Manager: Buddy Guynes, NASA Marshall Space Flight Center, Huntsville, AL



Boulders fresh from a tumble down a mountain are really grains of Ottawa sand used in civil engineering tests and in MGM. The craggy surfaces stick and form small voids between grains, causing soil or powders to behave like a liquid under certain conditions (below): (1) particles sticking to each other form a large hole, (2) a small strain collapses the hole, (3) another large strain forms more new holes, (4) which collapse when the strain reverses.

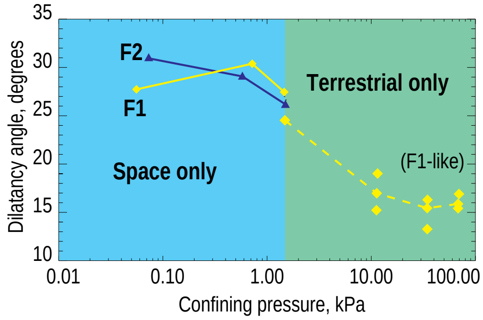


MGM has flown twice on the Space Shuttle (STS–79 and –89), involving nine dry sand specimens. These were highly successful, showing strength properties two to three times greater and stiffness properties ten times greater than conventional theory predicted. On STS–107, MGM scientists will investigate conditions with water-saturated sand resembling soil on Earth. Three sand specimens will be used in nine experiments. MGM can also benefit from extended tests aboard the *International Space Station*, including experiments under simulated lunar and Martian gravity in the science centrifuge.

Background Information

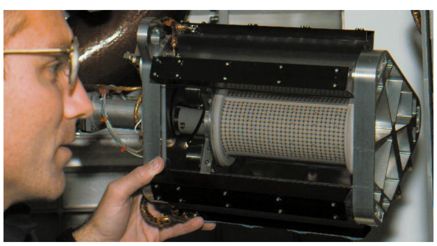
Science

The principal strength of particulate materials — such as soil beneath a house or sand under a rover's wheels on Mars — is friction and geometric interlocking between the faces of individual grains. Moisture and air trapped within the soil can also affect behavior if loading occurs faster than the entrapped fluid can escape. As the pore water pressure or air pressure increases, the effective or intergranular stresses or pressures decrease, weakening and softening the soil. When the external loading equals the internal pore pressure, the soil liquefies.

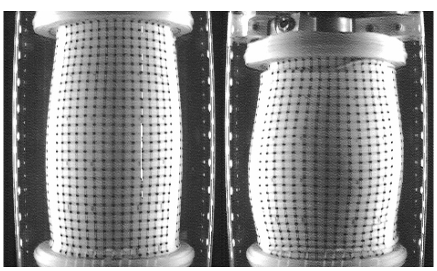


MGM experiments aboard the Space Shuttle in 1997 produced data that cannot be achieved on Earth.

The weightless environment of space allows soil mechanics experiments at low effective stresses with very low confining pressures. In space, specimen weight is no longer a factor, and the stress across the specimen is constant. This yields measurements that can be applied to larger problems on Earth. MGM scientists will study load, deformation, and fluid pressure data gathered during testing, as well as changes in the soil structure, including the formation of shear bands and changes in density.



Astronaut Carl Walz installs an MGM test cell on STS–79. Compression (below) takes about an hour.



Hardware

The heart of MGM is a column of sand held in a latex sleeve and compressed between tungsten metal plates. Each cell uses 1.3 kg (2.8 lbs.) of Ottawa F–75 banding sand, 7.5 cm in diameter by 15 cm tall (3 × 6 in.). Ottawa sand, a natural quartz sand (silicon dioxide) with fine grains (0.1 to 0.3 mm size), is widely used in civil engineering experiments and evaluations.

Affected Fields

Technologies: Storage, handling, processing and managing coarse grains materials and powders; silos, powder feeders, conveyors, and systems for processing coal, ash, limestone, cement, grain, pharmaceuticals, fertilizers.

Nature: Wind and river transport processes. During earthquake-induced liquefaction, the soil-water composite momentarily acts like a viscous liquid, allowing buildings to sink and tilt, bridge piers to move, and buried structures to float.

Applications

Soil mechanics, geotechnical engineering
Earthquake engineering
Mining of open pits, strip mines, tunnels, shafts
Grain silos, powder feed systems, coal, ash, pharmaceuticals, and fertilizers
Coastal and offshore engineering
Geology and geophysics of wind and water erosion of soil, slope development and decay, deposit of volcanic materials
Off-road vehicle engineering
Planetary geology
Microgravity handling of powders

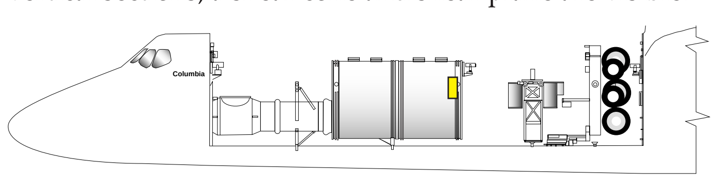
The specimen assembly is contained in a water-filled Lexan jacket. A load cell measures forces and three CCD cameras video tape the experiment. The flight crew controls the experiment through a laptop computer. The system takes the volume of four middeck lockers in the SPACEHAB module.

After return to Earth, epoxy is injected to stabilize the sand column for handling. The edge profiles are photographed. Computer tomography (CT) scans produce a series of 1024 × 1024-pixel images to make three-dimensional images showing internal details. Finally, the columns are sawed into 1 mm-thick disks for detailed inspection under an optical microscope.

CT scans of MGM specimens reveal internal features and patterns not seen in specimens tested on the ground.

Early Results

Several significant findings have emerged from the first two MGM flights and are helping scientists test a number of hypoptheses about soil behavior. Gravity appears to mask the true friction between sand grains. Unusually high peak friction angles of 47.6 to 70.0° were measured for μg specimens compared to 42 to 46° for 1-g specimens. CT scans show features unlike those seen in ground-based tests. Cross-sections have areas of generally uniform density outside of shear zones. Cross-sections at right angles to the axis of compression show lower and higher density areas seeming to separate into radial streams, tied together toward the center of the specimen, and at right angles to the outer surface. In vertical sections, a shear cone and shear plane are visible.



Approximate location of this payload aboard STS–107.

Picture credits. Earthquake damage: U.S. Geological Survey. Sand grains: Dr. Binayak Panda, IITRI. Grain cartoon: after T.L. Youd, "Packing Changes and Liquefaction Susceptibility," *Journal of the Geotechnical Engineering Division*, 103: GT8, 918-922, 1977. All others: NASA.